A MONOPULSE SYSTEM: APPLICATIONS FOR WEATHER RADAR OBSERVATIONS

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1. INTRODUCTION

Application of monopulse processing to weather radar has the potential to provide greater details on the circulation and shear of wind fields at sub-beamwidth resolutions, which are very important for, e.g., tornado detection.

For either the azimuthal or elevation plane, a monopulse system uses two identical beams, whose outputs are summed (even-mode) and subtracted (odd-mode). The antenna segments forming these beams are physically separated and the amplitude and phase of Doppler returns from these sub-apertures should show correlation. As a result, the radar reflectivity and Doppler velocity could be estimated at a sub-beamwidth resolution. The phased array radar of the National Weather Radar Testbed (NWRT) located at Norman, Oklahoma provides an ideal platform for implementing and evaluating the application of a monopulse system to weather observations

A sophisticated radar simulator developed at the University of Oklahoma (**?**) is modified to emulate the monopulse antenna system at the NWRT, with one transmitted beam and four spatially separated, quadrant-receivers. The emulator incorporates randomly distributed scatters which are advected to the times of radar pulses by time-dependent flows simulated by the ARPS (Advanced Regional Prediction System) model (Xue et al., 2000, 2001, 2003) at up to 100 m spatial resolutions. The returns from these scatters are integrated over the radar sampling volumes using realistic beam patterns. Radar reflectivity (Z) is calculated from model simulated hydrometeors.

In this study the evaluation of the monopulse system has been conducted on the condition that there is an airplane which is the hard target, and then statistical analyses will be performed on the data simulated by the enhanced emulator in monopulse mode, using very-high-resolution ARPS output of several types of weather conditions.

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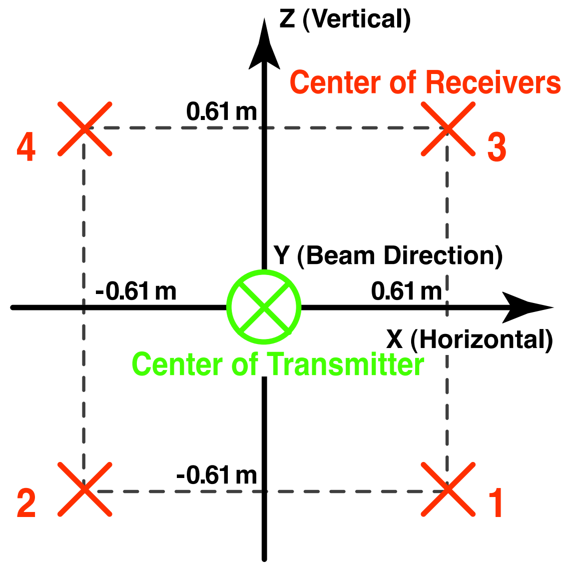

Figure 1: Diagram of transmitting and receiving antennas. The number of each receivers are also shown.

2. METHODOLOGY

The main idea of a monopulse system is to estimate the correlation of the "sum" and "difference" channels using two identical beams, whose outputs are summed (even-mode) and subtracted (odd-mode). In simulation we have one transmitter and four receivers for the monopulse system, whose beam width are 1.75°and 2.5°, respectively. The centers of these receivers are separated with 1.22 m in x-z coordinate and the beam is directed in y direction as Figure 1.

Table 1: Parameters for the ARPS forecasts.

Domain Size	64.3 $\times$ 64.3 km in 100 m grid 43 points vertically stretched up to 16 km height
Output	Pressure, Potential temperature, Mixing ratio of rain, 3-D wind (every 1 min)

The emulator can emulate volume scattering from atmosphere field using many point scatters, which are, for example, distributed targets of hydrometeors and hard targets of airplane **cite...**. The characteristics of these point scatters like their motion and reflectivity are determined by the input meteorological fields. In this study the forecasts of ARPS are used and the parameters of the forecasts are shown in Table 2. The meteorological fields at every scatter are interpolated in time and space. Coherently summed electromagnetic signals, which are backscattered from each of the point targets, can generate the time-series signal at the receiving antennas.

In the monopulse system, the ”sum” channel is generated by summing all the signals from the four receivers in time, on the other hand, the ”difference” channel is by extracting the signal each other in azimuth and elevation (Zhang and Doviak, 2007). The ”sum” and ”difference” beam patterns are shown in 2. That is, the ”sum” (S_{sum}) and ”difference” (S_{diff}) channels in the time domain are expressed by the signal from the four receivers S_n as:

$$S_{\text{sum}}(t) = \sum_{n=1}^{4} S_n(t) \quad (1)$$

$$S_{\text{diff}}(t) = \left(\sum_{n=1,3} S_n(t)\right) - \left(\sum_{n=2,4} S_n(t)\right) \quad (2)$$

$$\text{(in Azimuth)}$$

$$= \left(\sum_{n=3,4} S_n(t)\right) - \left(\sum_{n=1,2} S_n(t)\right) \quad (3)$$

$$\text{(in Elevation)}.$$

These signal are Fourier-transformed into the frequency domain. Then the monopulse ratio (DoS) are calculated as

$$DoS = \frac{S_{\text{diff}}(f)}{S_{\text{sum}}(f)}. \quad (4)$$

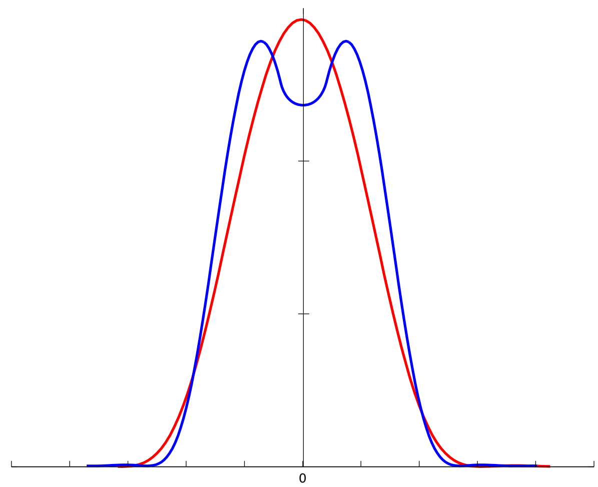

Figure 2: Beam patterns of ”sum” and ”difference” channels. Red and blue lines show ”sum” and ”difference” channels, respectively.

The angle (θ) from the center of the transmit beam is related to the monopulse ratio,

$$\theta = \sin^{-1}\left(\frac{2\pi D}{\lambda}\tan^{-1}\left[\text{Img}(DoS)\right]\right), \quad (5)$$

where Img denotes the imaginary part, D is the distance between the receivers, and λ is the wavelength, and the Doppler velocity (V_r) is related to the index number of the monopulse ratio as

$$V_r(n) = \frac{2V_a}{N_{\text{fft}}} \times (n - 1 - \frac{V_a}{2}), \quad (6)$$

where V_a is the aliasing velocity, N_{fft} is the number of FFT, n is the index number, respectively. Therefore, the Doppler velocity corresponds to the velocity at the specified location (θ).

3. PRELIMINARY RESULTS

3.1. Evaluate the Monopulse System

At first, we apply to the monopulse system for a point target in order to evaluate the simulation. An airplane is

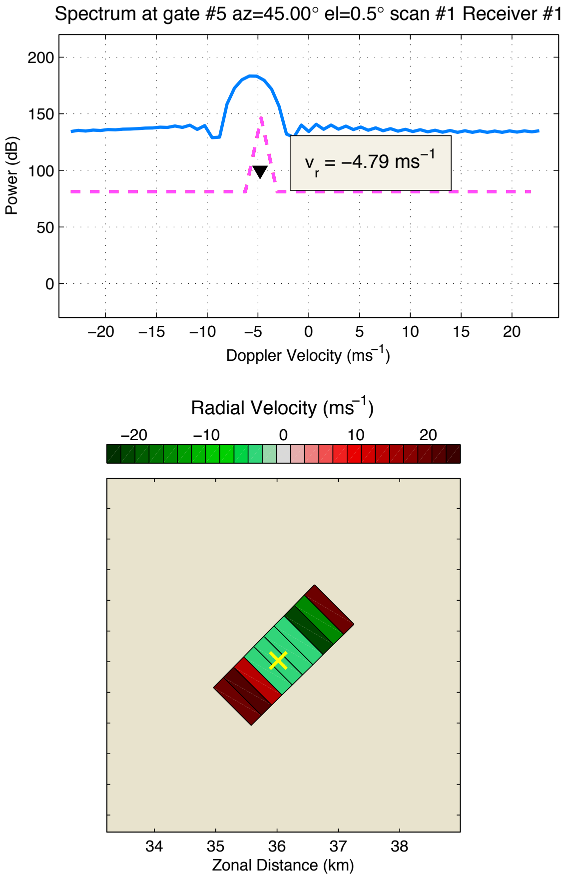

Figure 3: Horizontal distribution of Doppler velocity estimated through the pulse-pair system and power spectra. An airplane is at the fifth gate as shown by the red cross.

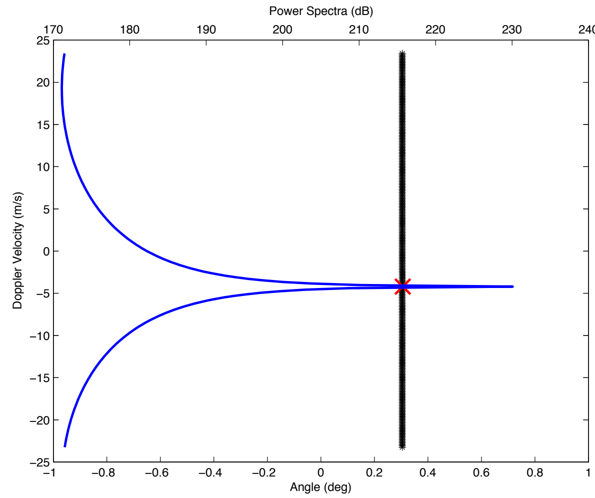

Figure 4: Cross-section of Doppler velocity, power spectra and the angle. Blue line shows the power spectra. Black dots denote Doppler velocity. Red cross shows the data which has the maximum power spectra.

at 0.3° off from the center of the radar beam, and moves 60 m s^{-1}in the direction of 45° away from the radar. As the aliasing velocity is 23.4 m s^{-1}in this simulation, the radial velocity of the airplane is -4.4 m s^{-1}. In the pulse-pair radar system (Figure 3) we can estimate the speed of the target, but we cannot determine the position within the volume, due to the limitation of the resolution. As shown in Figure 4, we can exactly estimate the speed and position of the target by the monopulse system.

3.2. Wind Shear Condition

As a simple case, the radial velocity field is changed from -15 m s^{-1}to 5 m s^{-1}with the constant rate in the radar volume. As shown in Figure 5, the estimated radial velocity is slightly different from the true wind, however this motivates us to apply this technique to target signatures from specific wind field patterns of interest.

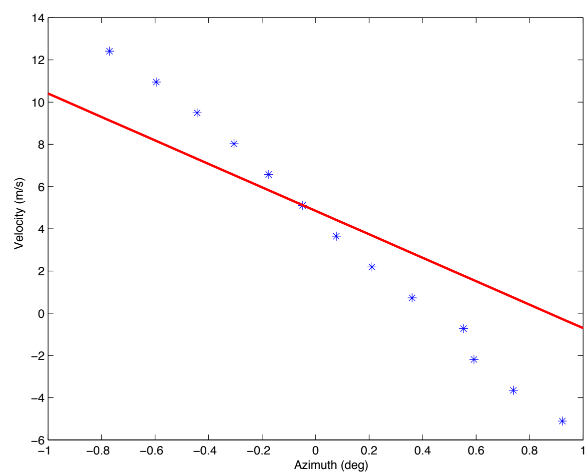

Figure 5: Cross-section of Doppler velocity and azimuth angle. Blue dots denote the estimated Doppler velocity. Red line shows the true Doppler velocity.

4. CONCLUSION

We applied the monopulse system to the radar emulator developed at the OU. In order to demonstrate the feasibility of the monopulse system and simulator, a hard target of an airplane is set at the specified gate in the radar volume. Although the Doppler velocity can be estimated but the position is unfair through the pulse-pair system, both the Doppler velocity and angular position in the radar volume can be estimated well.

We are still working to apply various meteorological conditions, for example, an uniform reflectivity and wind field, a strong wind shear field in the radar volume, and so on.

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